An introduction to gEcon

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DSGE models (1/2)

- DSGE (Dynamic Stochastic General Equilibrium) models are dynamic macroeconomic models derived from microeconomic principles (optimisation, market clearing, rational expectations).
- (Very) short history of DSGE modelling:
  - '70s — the appearance of new-classical macroeconomic school — first dynamic rational expectations (RE) and dynamic general equilibrium models
  - '80s — the seminal work of Kydland and Prescott (1982) (dawn of RBC school)
  - '90s — monopolistic competition and price rigidities are added to RBC models by Rotemberg and Woodford (1997)
  - '00s — Christiano, Eichenbaum, Evans (2005) model and estimated modification by Smets and Wouters (2003)
  - Nowadays, DSGE models are used across the globe by central banks and governments for policy analysis

DSGE models (2/2)

- DSGE models are complex and non-linear — they have to be solved using numerical methods
- In the '80 the numerical approach usually involved the linear-quadratic (LQ) approximation and the entire model model had to be implemented from scratch (mostly in FORTRAN)
- In the '90 MATLAB gained popularity and the first DSGE toolbox was released by Harald Uhlig, followed by a toolbox by Christopher Sims — both are based on the 1st order perturbation (the non-linear model is approximated by a linear RE model), the researcher had to derive the First Order Conditions (FOCs) and perturbation matrices
- Dynare project was a natural next step in the development of DSGE tools — only FOCs have to be derived, perturbation matrices are determined using symbolic computations

CGE models

- CGE (Computable General Equilibrium) models are a class of (generally static) applied economic models descending from the Input-Output models but based on microeconomic principles (optimisation and market clearing)
- CGE models have a long history with first models build in the '60s (Leif Johansen (1960)) and '70 (Taylor and Black (1974))
- CGE models are mostly used for comparative-static analyses of impact of external shocks or policy changes
- Initially, CGE models were written and implemented on a computer from scratch
- Curretly, most models are implemented in GAMS or GEMPACK frameworks, which allow for compact expression of similar equations differing by indices (of producers, households) and parameter values only

gEcon project objectives

- The ultimate goal of gEcon is to **reduce the development time of large-scale DSGE and CGE models for policy analysis and provide a unified framework for development of these two classes of models**
- The models are to be written — whenever possible — in terms of optimisation problems of agents without the need to manually derive the FOCs; symbolic manipulations on the part of the user should be kept to bare minimum
- The models should be easily scalable — the size of the model should not grow with the no. of sectors / types of households — a template mechanism is essential
- The process of solving the model should be interactive — the user should be able to change some parameters without the need to recompute the model
- The design of the package should allow for adding new functionalities and building solutions / packages on top of it

Main characteristics

- gEcon was developed as an R package — this choice (most DSGE packages are written in MATLAB) was motivated by R language flexibility and natural synergies between economic modelling and econometric work
- gEcon is based on a comprehensive symbolic computations library supporting symbolic differentiation, FOCs derivation, equation templates (including template differentiation), and symbolic reduction
- R interface is object-based, built around gecon_model class with a comprehensive set of functions useful for model analysis and debugging
- gEcon if focused on model equations derivation and solution but can be easily extended — as opposed to "black box" solutions — e.g. to allow for model estimation (gEcon.estimation package) and calibration using Input-Output or Social Accounting Matrices (gEcon.iosam package)

gEcon language (1/2)

- gEcon language should be easily understood by anyone with some exposure to R or MATLAB, variables (K[] — K_t) and parameters (alpha — α) are written in a natural way
- All standard mathematical operations (+, -, *, /, ^) and functions (log, exp, sin, ...) are supported
- Models are organised in blocks corresponding to optimising agents or equilibrium conditions:

```
block FIRM
{
    controls
    {
        K_d[], L_d[], Y[];
    };
    objective
    {
        pi[] = Y[] - L_d[] * W[] - r[] * K_d[];
    };
    constraints
    {
        Y[] = Z[] * K_d[] ^ alpha * L_d[] ^ (1 - alpha);
    };
};
```

gEcon language (2/2)

- Template support in gEcon is natural:

```
alpha<s>         # parameter alpha indexed with free index s
alpha<'AGR'>     # parameter alpha indexed with 'AGR'
Y<c>[]           # variable Y (at time 0) indexed with free index c
Y<'PL'>[]        # variable Y (at time 0) indexed with 'PL'
EX<'PL',c>[]     # variable EX (at time 0) indexed with index 'PL' and free index c
eta<'PL','DE'>   # parameter eta indexed with index 'PL' and index 'DE'
```

- . . . and allows for compact formulation of model equations:

```
CD[] = PROD<f::FACTORS>(C<f>[] ^ alpha<f>);
CES[] = (SUM<g::GOODS>(share<g> * D<g>[] ^ ((eta - 1) / eta))) ^ (eta / (eta - 1));
```

gEcon will understand these expression as:

$$CD_t = \prod_{f \in FACTORS} {C_t^{\langle f \rangle}}^{\alpha^{\langle f \rangle}},$$

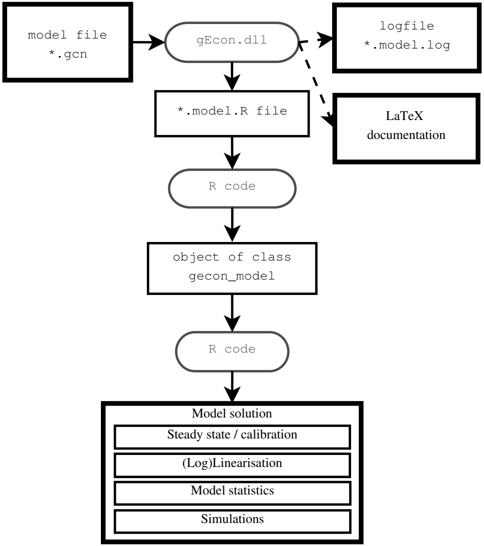
$$CES_t = \left(\sum_{g \in GOODS} share^{\langle g \rangle} {D_t^{\langle g \rangle}}^{(\eta - 1)/\eta} \right)^{\eta/(\eta-1)}.$$

Model solution procedure (1/3)

1. Models (optimisation problems of agents, equilibrium relationships, etc.) are written in gEcon language in a .gcn file
2. Models are read from R using the make_model function:

   ```
   > model <- make_model("PATH_TO_FILE/model.gcn")
   ```
3. the make_model function calls a shared library (DLL) that performs symbolic computations and then creates objects of class gecon_model in our workspace in R; in addition, logfile and LaTeXdocumentation of the model can be produced by the DLL
4. R scripts can then be used for solving the models (steady state / equilibrium computation, perturbation), simulation, and analysis

Model solution procedure (2/3)



Model solution procedure (3/3)

gEcon R interface was meant to be simple and intuitivee. Model construction and solution comes in few simple steps:

- Read model from .gcn file:

```
> model <- make_model("model.gcn")
```

- Find the steady state:

```
> model <- steady_state(model)
```

- Solve the 1st order perturbation:

```
> model <- solve_pert(model)
```

- Compute model statistics:

```
> model <- compute_model_stats(model = model,
                                ref_var = 'Y')
```

- Get information about selected model variables:

```
> var_info(model, c("Y", "C", "I"))
```

Model calibration using gEcon.iosam package

- Calibration of large-scale CGE and DSGE models using Input-Output Tables and Social Accounting Matrices can become a difficult and tedious task due to the number of parameters involved
- gEcon.iosam package is designed to assist users in this task by providing iosam class for representing Input-Output Tables and Social Accounting Matrices and a set of functions for importing and manipulating them
- To streamline the process of calibration of CGE (and multisector DSGE) models written using gEcon template mechanism, the function get_flow_values is provided

```
> model <- set_free_par(model, c(k_f_data    = sam["Firms", "K"], ks_data     = sam["SUM", "K"],
                                 ls_data     = sam["SUM", "L"], omega       = 2,
                                 get_flow_values(sam["L", sam_prod], "l_data", gcn_prod),
                                 get_flow_values(sam["SUM", sam_prod], "y_data", gcn_prod),
                                 get_flow_values(sam[sam_prod, sam_prod], "x_data", gcn_prod,  gcn_prod),
                                 get_flow_values(sam["Large_hh", "Firms"], "cap_data", "1"),
                                 get_flow_values(sam["Large_hh", "L"], "l_data", "1"),
                                 get_flow_values(scale_h, "scale",  gcn_hhds),
                                 get_flow_values(sam[sam_hhds, "K"], "k_data", gcn_hhds),
                                 get_flow_values(sam[7:8, sam_hhds], "d_data", c("B", "C"), gcn_hhds)
                                 ))
```

Model estimation using gEcon.estimation package (1/2)

- The gEcon.estimation package uses the state-space representation of models for likelihood computation (using Kalman filter) and estimation (Bayesian estimation or maximum likelihood approach).
- Additional functionalities include: forecasting functions, Kalman smoother for the model variables, historical shock decomposition.
- To estimate a model the user has to supply data (as ts objects), solved DSGE model (an object of gecon_model class), and prior distribution for parameters (six families of distributions are provided).

Model estimation using `gEcon.estimation` package (2/2)

- The Bayesian estimation is implemented in a standard way:
  - solver finds the mode and the standard deviation of the posterior kernel,
  - random walk Metropolis-Hastings routines are run to simulate the posterior.
- The results are stored in an `R` object.
- The flexible design makes the analysis of estimated model properties convenient (e.g. there is no need to re-estimate the model when changing forecast or smoother settings).

gEcon use cases

- Implementation of the Smets-Wouters '03 model — gEcon implementation led to revealing two mistakes in the manual derivation of model equations, https://ideas.repec.org/p/pra/mprapa/64440.html
- International trade CGE model calibrated using the GTAP database — implemented at the Department for Strategic Analyses at the Chancellery of the Prime Minister of the Republic of Poland
- CGE model for fiscal policy impact assessment — implemented at the Department for Strategic Analyses at the Chancellery of the Prime Minister of the Republic of Poland